A DYNAMIC GRASPING ASSESSMENT SYSTEM FOR MEASURING FINGER FORCES DURING WRIST MOTION

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Abstract - *A device that provides quantitative assessment of the grasping function and allows grasping function improvements to be monitored over time can potentially be very useful for hand surgeons, physiotherapists and occupational therapists. A Dynamic Grasping Assessment System (DGAS) that is capable of measuring finger forces during wrist extension, flexion, adduction and abduction was developed. The DGAS can measure forces for each individual finger in the range from 0 to 125 N with accuracy of $\pm$ 0.5 N, and can measure the wrist extension/flexion angle and the wrist ulnar/radial abduction angle with an accuracy of $\pm$ 0.25 deg. Furthermore the DGAS is capable of generating resistive torque during the wrist motion and allows to assess finger forces during wrist motion against resistive load. The DGAS can provide the following data: (1) finger forces as a function of time, wrist angle, wrist angular velocity and resistive load; (2) statistical analysis of the recorded finger force data; (3) drifts of the finger forces as a result of fatigue; and (4) the range of wrist motion for a given resistive load. Further analysis of the measured data, e.g. correlation analysis between the finger forces and the wrist angles, can be done off-line.*

Introduction

Quantitative grasping assessment methods are either based on grasping skill tests or grasping force measurements. Grasping skill tests [1, 2] quantify the grasping performance using sets of objects that have to be grasped, moved and released. They can be used for the functional assessment of neuroprostheses in daily living activities, as they help to quantify the grasping performance. Grasping skill tests assess very strongly the subjects' skills and training efforts, but, for example, to assess the optimal placement of stimulation electrodes of neuroprostheses grasping force measurement devices are more suitable. They measure the force of the hand or the forces of each finger during a palmar or a pinch grasp. Simple devices like mechanical power-grasp dynamometers measure the peak forces applied by all fingers against the palm. More sophisticated electronic dynamometers allow power- or pinch-grasp forces to be measured over time. For example, the NK DIGITS-Grip™ device can determine the contribution of the individual fingers to the grasp. The tool consists of a electronic dynamometer with four additional finger force sensors.

The presented dynamic grasping assessment system (DGAS) was developed for the assessment of the grasping force of each digit during wrist motion. Since every muscle produces different forces for different muscle lengths, a change in the finger flexion force can be observed for different wrist angles.

The aim of this article about the DGAS is to give a full description of the DGAS and all its components. Further first measurements obtained from 5 healthy subjects are discussed and compared with data from the literature.

Methods

The DGAS was built as a mountable platform for the BTE work simulator which is a device for functional training and evaluation of the maximum strength, power and endurance of upper extremities. Using the BTE work simulator, the wrist rotation could be locked or loaded with resistive torque.

Platform

The system consisted of the following parts(see Figure 1):

- A platform that was fixed to the head of the BTE work simulator
- A grasping measurement device that allowed an exact alignment of the grasping handle to the measured hand and housed an encoder for measuring the wrist angles
- A grasping handle that incorporated five strain gage force sensors (see Figure 1 upper right)
- A data acquisition and processing hardware and software that recorded the measurements of the forces, the angles and the subjects data.

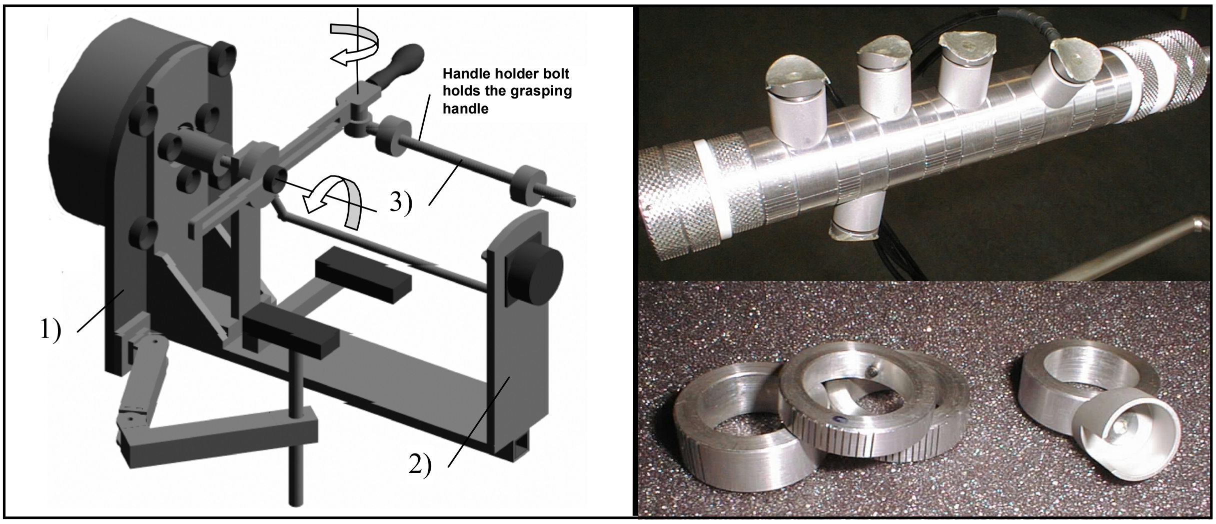


Figure 1: The handle of the DGAS (right picture) can be adjusted in four degrees of freedom. Thus the rotational axis of the wrist joint can be adjusted to the BTE working simulator axis.

Grasping Handle and Sensors

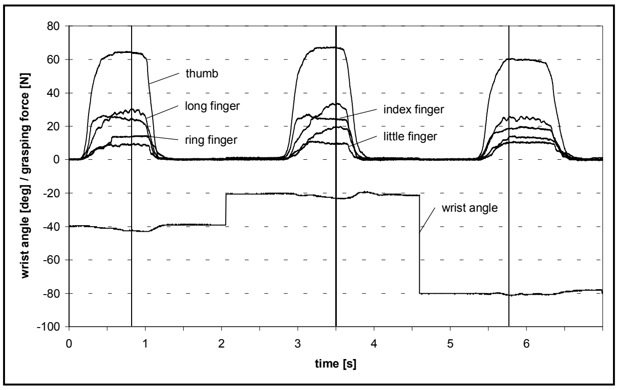
For the assessment of the grasping force generated by a neuroprosthesis the grasping handle should be able to measure the finger forces at different phalanges and for different hand sizes. We decided to develop a very flexibly configurable grasping handle. It consisted of a hollow cylinder on which five sensor holder rings and several separator rings (see Figure 1 bottom right) with different sizes could be assembled. The sensor holder rings could be rotated about the cylinder axis and therefore could be precisely placed under the targeted phalanges. The handle was adjusted to the width of different hands, using separator rings with 4, 6, 8 and 10 mm thickness that were placed between the sensor holder rings. On each separator ring an angular scale was scribed. A groove in the hollow cylinder and press-fitted pins in each separator ring prevented the separator rings to rotate with respect to the hollow cylinder. Therefore the rotation angle of each sensor holder ring could be read off very easily.

Extra small Entran strain gage load cells ELFM-B1-125 N were placed into each sensor holder ring (see Figure 1 upper right). The sensors measured pressure forces in the range of 0 N to 125 N. A metal housing for each sensor was designed to avoid damaging the very delicate load cells. The housing construction guaranteed that only orthogonal forces loaded the cell.

Results

First measurement results were obtained from the dominant hand of 5 healthy subjects. After adapting the DGAS to the subjects' hand, they were asked to exert maximal isometric force on the handle for 2 seconds for different wrist angles. In these first trials different wrist extension/flexion angles were evaluated. The range of the measured wrist angles was from -80º to +60º using 20º steps. Every angle was measured five times randomly distributed. Between two trials a pause of minimal 20 s was introduced to avoid muscle fatigue.

Twenty samples of each trial were averaged about the maximum thumb force to determine the maximum finger forces of each finger. For each subject the mean and the standard deviation of the five trials for each wrist angle was calculated. All forces were normalized for each wrist angle to the sum of the maximum index, long, ring, and little finger forces. Figure 2 right shows the normalized results of one subject and Table 1 shows the average of all five subjects compared to data found in literature.



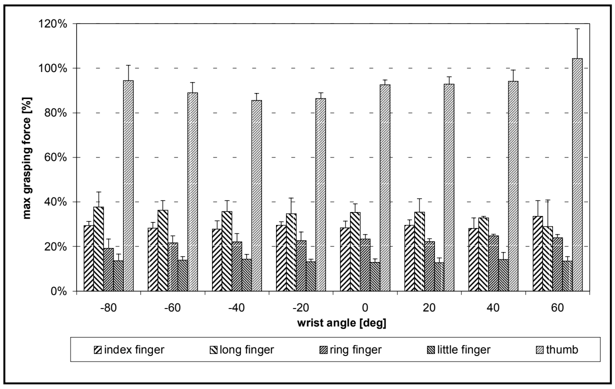


Figure 2: The left figure shows the raw data of the measured finger forces and the wrist angle. The right figure shows the average maximum finger forces of all 5 fingers from one subject for different wrist angles. The forces are normalized to the sum of the maximum index, long, ring, and little finger forces.

DGAS, five subjects summed							Hazelton et al. 1974 [3]	Amis 1987 [4]	Radhakrishan and Nagarvindra 1993 [5]
wrist angle	-40º	-20º	0º	20º	40º	60º	**	*	*
index finger	34%	30%	29%	31%	30%	32%	25.4%	30%	31%
long finger	29%	30%	31%	29%	29%	29%	33.9%	30%	33%
ring finger	20%	22%	23%	22%	24%	22%	25.2%	22%	22%
little finger	17%	18%	17%	18%	17%	17%	15.2%	18%	14%

* left up to the subject

** experiments were done for five different angles; no significant difference for different angles were reported

Table 1: A comparison of our results of the percentage digital force distribution to the total finger force with studies done by Hatzelton et al. (1974), Amis (1987), and Radhakrishan, Nagaravindra (1993) showed similar results.

Discussion and Conclusion

The presented DGAS is capable of measuring the grasping force of each finger during dynamic wrist motion against torque. In our opinion this represents a novelty in dynamic grasping assessment.

Our first results obtained with 5 able bodied subjects showed that the DGAS can be adjusted to different hand sizes and provides consistent quantitative data about the grasping force distribution among the fingers for different wrist angles. Standard deviations of less than 10% (see Figure 2 right), except for extreme wrist angles, were a very good indication for consistent data, in spite of the small number of trials per wrist angle.

A comparison of the measured data with studies done by Hatzelton et al. (1974), Amis (1987), and Radhakrishan and Nagaravindra (1993) [3-5] indicated that the DGAS is capable of measuring consistent grasping forces for different subjects.

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